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Energetics of the NMC Final Cycle

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I. Introduction

One of the diagnostic tools used to evaluate analyses generated during the preimplementation test of the 6-hour cycle (Desmarais et al., 1976) is the energy program developed by Miller et al., 1975. The preimplementation test served to evaluate the impact of shortening the update interval of the NMC Final cycle from 12 hours to 6 hours. Based on the results of that test, the shorter update interval is being used operationally. However, the energy differences between analyses made with the 12-hour cycle and those made with the 6-hour cycle were neither completely explained nor understood. Fortunately, for most times and for most energy types, there proved to be very little difference between 6- and 12-hour cycles. But for some energy types, particularly the kinetic energy in the Southern Hemisphere, the differences were fairly substantial. The purpose of this note is to attempt to shed a little more light on why the energy differences occurred.

II. Description of the preimplementation test

The preimplementation test covered the period August 27-September 6, 1976. The 12-hour cycle consisted of the then operational final analysis/forecast cycle, which utilizes the global spectral analysis technique (Flattery, 1970) and the 9-layer global prediction model (Stackpole, 1976). The 6-hour cycle was identical to the 12-hour cycle except observations were inserted twice as frequently. All asynoptic reports were treated as though synoptic. Hence, data differing from synoptic time by as much as 6 hours were used in the 12-hour cycle, whereas data used in the 6-hour cycle never differed from synoptic time by more than 3 hours. Synoptic reports taken at 06 and 18 GMT were not used in the 12-hour cycle, but were used in the 6-hour cycle. Because of the times at which the observational data files had to be dumped and archived, some asynoptic reports (aircraft winds and VTPR) available to the 12-hour cycle analyses did not get into the 6-hour cycle analyses. The net effect was for there to be more data available to the 6-hour cycle than the 12-hour cycle. Most of these extra observations were located at the surface.

III. Energy results and discussion

Among other things, the energy program calculates zonal available (AZ), eddy available (AE), zonal kinetic (KZ), and eddy kinetic (KE) energy for a variety of latitudinal belts and vertical extents. These parameters, which are calculated as described in NMC Office Note 109, were monitored carefully during the preimplementation test. Several plots of these parameters are shown in Figures 1-10. All energy parameters are computed from analyzed temperature and wind fields located on a 2.5° resolution latitude/longitude grid. Calculations from the 6-hour cycle analyses for 06 and 18 GMT are not presented since there are no corresponding values from the 12-hour cycle.

Some of these figures are presented without very much comment; the purpose of presenting them is to show that for some energy parameters the 6-hour cycle behaves very much like the 12-hour cycle. Two such diagrams are shown in Figures 1 and 2: the zonal available and eddy available energy for the Northern Hemisphere for the layer 1000 to 100 mb. The most striking feature of both these diagrams and especially the AE diagram is the diurnal oscillation, the AE being lower at 12 GMT than at 00 GMT. This feature has always been a characteristic of the 12-hour cycle. The 6-hour cycle has the same characteristic. At the present time, the author is not aware of a satisfactory explanation for this characteristic. Both the AZ and AE are slightly higher in the 6-hour cycle analyses. However, the difference is small.

The AZ and AE for the Southern Hemisphere (Figures 3 and 4) show larger differences between 6- and 12-hour cycles than in the Northern Hemisphere. However, these differences do not appear to be systematic. Generally speaking, the behavior of the 6-hour cycle is similar to that of the 12-hour cycle. The differences are probably greater in the Southern Hemisphere than in the Northern Hemisphere, because a much larger percentage of the data is asynoptic in nature in the Southern Hemisphere. A large percentage of the Southern Hemisphere data consists of satellite soundings (VTPR). Thus, going to a different time treatment of the data is more likely to produce differences in the Southern Hemisphere. Also, the fact that some asynoptic observations did not get into the 6-hour cycle data base is bound to have a bigger impact on the Southern Hemisphere.

The kinetic energies produced the most interesting results. Figures 5-10 are plots of kinetic energy, both zonal and eddy, for each hemisphere. Kinetic energies for the 6-hour cycle and 12-hour cycle analyses are very nearly identical in the Northern Hemisphere at all levels. This fact is exemplified by Figures 5-8 which show the zonal and eddy kinetic energies at 300 and 700 mb. Such is not the case in the Southern Hemisphere where the differences are quite large in the upper troposphere. Figures 9 and 10 show comparisons at 300 mb. At this level, the KZ and KE are both systematically lower in the 6-hour cycle analyses than in the 12-hour cycle analyses. A graphic example of the loss of kinetic energy which occurs in the 6-hour cycle can be seen in the 00 GMT September 6 isotach pattern at 300 mb (Figure 11). Nearly every isotach maximum is slightly stronger on the 12-hour cycle analysis than on the 6-hour cycle analysis. At low levels the 6-hour cycle KZ and KE are not systematically lower than in the 12-hour cycle as can be seen from the vertical profiles of KZ and KE in Figures 12 and 13. These profiles are averaged over 20 cases. The largest percentage difference occurs in the KE at upper tropospheric levels.

In order to better understand how the loss of Southern Hemisphere kinetic energy occurs, the energy program was executed at various points in the analysis/forecast cycle. The major steps in the 6-hour analysis/forecast cycle are:

1. vertical interpolation of analysis from pressure surfaces to model coordinates,

2. forecast made to 6 hours,

3. vertical interpolation of forecast from model coordinates to pressure surfaces,

4. transformation of forecast to spectral space to obtain first guess coefficients,

5. spectral analysis of observational data starting from first guess coefficients,

6. transformation of analysis from spectral space to real space on pressure surfaces.

At each step enumerated it is possible that a loss of kinetic energy could take place. It would, therefore, be instructive to execute the energy program at each of these steps. However, the program is not constructed to work in the model's sigma coordinate system, but rather only on constant pressure surfaces. Hence, it is not possible to directly measure the change in energy that occurs during the vertical interpolation to or from the model coordinate system. Nor is it possible to directly measure the gain or loss of energy that might occur during the course of a 6-hour forecast. However, these energy changes were estimated in the following manner. The analysis, after having been constructed on 12 mandatory pressure surfaces, was interpolated to the model coordinate system. This analysis (in sigma) was then interpolated back to the 12 mandatory pressure surfaces. One-half of the energy change was assumed to have occurred during the interpolation into sigma and one-half during the interpolation from sigma to pressure. By adding one-half of the energy change to the energy of the analysis in pressure, the energy at the start of the forecast (in sigma) is obtained. Similarly, by interpolating the subsequent 6-hour forecast (interpolated to pressure) from pressure to model coordinate and then back to pressure, assuming again that half the energy change occurs going into sigma and half coming out, an estimate of the energy at the end of the 6-hour forecast (in sigma) can be made.

Following the above procedure, the kinetic energy levels at each of the six points enumerated above were estimated for the 12-hour period beginning at 00 GMT August 28. The results for the 300-mb KE and KZ are shown in Figures 14 and 15 for the Southern Hemisphere. Looking first at the KE (Figure 14), it can be seen that at 00 GMT a loss of about 8 j/kg occurs in the interpolation from pressure to sigma (A(p) to A(σ)). The forecast model then increases the KE by 4 j/kg during the course of the forecast (A(σ) to F(σ)). The interpolation to pressure (F(σ) to F(p)) then results in a loss of 4 j/kg. A little more is lost in the transformation to spectral space (F(p) to FG(p)), followed by a slight increase during the analysis of data (FG(p) to A(p)), and then another loss due to the vertical interpolation to sigma (A(p) to A(σ)). The net energy loss due to the interruption of the model and insertion of data (F(σ) to A(σ)) at 06 GMT is 11 j/kg. The model than gains KE during the next 6-hour forecast segment (A(σ) to F(σ)). This gain is followed by an 8 j/kg loss in the interpolation to pressure (F(σ) to F(p)). A small loss occurs in the spectral transformation (F(p) to FG(p)), and then another small loss occurs during the analysis of observational data. The loss during the analysis at 12 GMT is different from what usually occurs; generally, the KE tends to increase such that the KE of the analysis is higher than that of the first guess. The values for the 12-hour cycle analyses and first guesses for 00 and 12 GMT are also plotted for comparison. The KZ (Figure 15) shows about the same pattern of behavior as the KE. It appears then that the greatest loss of kinetic energy occurs in the vertical interpolations, both to and from the model coordinates. Since these interpolations are performed twice as often in the 6-hour cycle as in the 12-hour cycle, it seems logical that the level of kinetic energy would be lower for the 6-hour cycle. The analysis usually raises the level of kinetic energy but does not completely compensate for the loss caused by the interpolations.

The fact that the loss of kinetic energy occurred only in the Southern Hemisphere could be explained by the fact that many more wind observations are present in the Northern Hemisphere. Presumably in the Northern Hemisphere the kinetic energy lost in interpolations would be regained during the analysis of data. In other words, the low energy first guess would be corrected by wind observations nearly everywhere.

A graphic illustration of what happens if the model is simply interrupted at 06 and 18 GMT without inserting any data is shown in Figure 16. The parameter plotted is total global kinetic energy in the uppermost tropospheric sigma layer. This parameter is generated by the global forecast model at each time step and is not the same program used for the rest of the energy calculations presented in this paper. The dashed curve depicts the kinetic energy when the model is interrupted at 12-hour intervals with data inserted each time the model is interrupted. The solid curve shows what happens if additional interruptions occur at 06 and 18 GMT without inserting data. The interruption process consists of vertically interpolating the forecast in sigma to pressure surfaces, transforming the forecast to spectral space, regridding the spectralized forecast on pressure surfaces, and interpolating to the model sigma coordinate system. In other words, the six steps enumerated above are executed except no new data are introduced. A substantial loss in kinetic energy occurs during the interruption process at 06 and 18 GMT. Introducing data at 00 and 12 GMT into the 6-hour cycle fails to bring the kinetic energy of the 6-hour cycle up to that of the 12-hour cycle.

There is some evidence which suggests that the loss of kinetic energy noted in the 6-hour cycle analyses during the preimplementation test may not always be confined to the Southern Hemisphere. The loss may be related to the strength of the winds since similar losses can be found in the Northern Hemisphere during the Northern Hemisphere winter season especially in areas of strong winds. One such example is shown in Figure 17. Figure 17a is the 6-hour cycle height/isotach analysis and Figure 17b is the corresponding 12-hour cycle analysis at 300 mb for February 14, 1976. Unfortunately, there are other differences than just update frequency between these two cycling systems. For example, the 12-hour cycle was run with an 8-layer version of the global model whereas the 6-hour cycle was run with a 9-layer version. Hence, drawing hard and fast conclusions may be somewhat dangerous. Several of the isotach maxima are slightly weaker on the 6-hour cycle analysis than on the 12-hour cycle analysis. In Figure 18, the 90-knot isotach contours (for both 6- and 12-hour cycles) over the Pacific Northwest are depicted for the same case along with actual wind speed reports from several radiosonde stations. The 12-hour cycle analysis draws more closely for the reported wind speeds. The 6-hour cycle analyzed wind speeds are too weak. Subjective comparison of several cases suggests that the difference in kinetic energy in the Northern Hemisphere between the 6- and 12-hour cycles is smaller during the Northern Hemisphere winter than the corresponding Southern Hemisphere differences during the Southern Hemisphere winter. This result is probably due to the presence of many more wind reports in and near the jetstream in the Northern Hemisphere than in the Southern Hemisphere.

IV. Summary and conclusions

Several energy statistics have been shown comparing the NMC 12-hour analysis/forecast cycle to the newly operational 6-hour cycle. The available energies of the two systems show similar trends with time and only small systematic differences. The kinetic energy comparisons reveal somewhat larger differences between the two systems. The kinetic energy of the 6-hour cycle is less than that of the 12-hour cycle, particularly in the Southern Hemisphere in areas of wind speed maxima. Limited evidence suggests that the kinetic energy is also slightly less in the 6-hour cycle in the Northern Hemisphere during the Northern Hemisphere winter, again in areas of wind speed maxima. The higher kinetic energy level of the 12-hour cycle is considered to be slightly closer to reality.

The lower level of kinetic energy in the 6-hour cycle is due to losses occurring during the two additional model interruptions which are needed to insert data at 06 and 18 GMT. A large percentage of the loss occurs during the vertical interpolations between pressure surfaces and the model coordinate system. If the spectral analysis is not replaced in the Final cycle by the optimum interpolation method in the near future, it would probably be a good idea to modify the vertical interpolation scheme such that the kinetic energy would be more nearly conserved.

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